Hazard Profile – Landslide

Introduction[1, 2, 3]

Landslide is the movement of rock, soil and debris down a hillside or slope. Landslides take lives, destroy homes, businesses, and public buildings, interrupt transportation, undermine bridges, derail train cars, cover marine habitat, and damage utilities.

The term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Ground failures that result in landslides occur when gravity overcomes the strength of a slope. While gravity is the primary reason for a landslide, there can be other contributing factors, including:

- Saturation, by snowmelt or heavy rains, that weaken rock or soils on slopes.
- Erosion by rivers, glaciers, or ocean waves that create over-steepened slopes.
- Topography of a slope – its shape, size, degree of slope and drainage.
- Stress from earthquakes magnitude 4.0 and greater can cause weak slopes to fail.
- Volcanic eruptions that produce loose ash deposits and debris flows.
- Excess weight, from accumulation of rain or snow, from stockpiling of rock or ore, from waste piles, or from manmade structures, may stress weak slopes to failure.
- Human action, such as construction, logging or road building that disturbs soils and slopes.

Landslides occur where certain combinations of geologic formations are present. For example, groundwater can accumulate and zones of weakness can develop when layers of sand and gravel lay above less permeable silt and clay layers. In the Puget Sound region, for example, this combination is common and widespread; glacial outwash, often Esperance Sand or gravel, overlies the fine-grained Lawton Clay or Whidbey formation.

Commonly, landslides occur on slopes and in areas where they have taken place before, as well as in areas where they have not been previously documented. Areas historically subject to landslides include the Columbia River Gorge, the banks of Lake Roosevelt, the Interstate 5 corridor, U.S. 101 Highway corridor along the Pacific Coast and from the coast to Olympia, the Cascade and Olympic mountain ranges, and Puget Sound coastal bluffs.

Determining probability of future landslide events is difficult because so many factors can contribute to the cause of a landslide or ground failure. (see above). Scientists from the U.S. Geological Survey are testing a pilot system that warns of increased risk of landslides in Seattle during certain heavy rainfall events. Such a system is possible, and only applies to Seattle, because the city has extensive records of landslides covering nearly a century.

Landslide Provinces[4]

Washington State has six landslide provinces, each with its own characteristics.

Puget Lowland – North Cascade Foothills

This landslide province is that portion of the Puget Lowland overridden by ice during the last continental glaciation. It has abundant rain, or in the foothills, rain and snow. This province also contains the largest and fastest growing population in the state.

Unconsolidated material overlies the bedrock of much of the Puget Lowland. Sculpting and compacting of the lowland by the last continental ice sheet combined with runoff and wave action to cut hundreds of miles of steep bluffs into these sediments. Many of these bluffs are in or near population centers; demand for residential development is great on these bluffs because of views from the top or access to the beach below.

Of these bluffs, those along the Puget Sound have been the most systematically studied. Slope stability maps of the Coastal Zone Atlas (Washington Department of Ecology, 1978-1980) show more than 660 miles of these bluffs as unstable.

The bluffs of the Puget Lowland are susceptible to landslides for a variety of reasons – their steepness, abundant rainfall and resulting groundwater, and contrasts in permeability of the materials. Four landslide types affect these bluffs:

- *Slump* – This type of landslide occurs when groundwater concentrates near compact silt or clay in the lower bluff area; the existence of a saturated zone can cause the sandy-soiled, upper bluff to subside, sometimes with accompanying backward rotation. This type of landslide tends to leave a distinctive mid-bluff bench. Examples of upper-bluff slumping can be seen in the Alki, Fort Lawton, and Golden Gardens areas of Seattle, Scatchet Head on Whidbey Island, and the Thorndyke Bat area of Jefferson County.

- *Debris flows* – Excessive groundwater combined with focused surface runoff commonly turn a landslide into a debris flow. These landslides commonly gain speed as they flow down the slope. They are capable of great destruction because their weight and viscosity enable them to move logs and houses; even a small debris flow can smash through the wall of a frame house or drop uprooted trees through a roof.

- *Ancient landslides in unconsolidated materials* – Ancient landslides in the thick sediments of the Puget Lowland are a concern because of their large size, the difficulties in recognizing them, and development pressure, especially in shoreline areas. Reactivation of such slides generally occur slowly and may consist of a few feet of movement in a particular episode, usually in the spring after an unusually wet winter. Even a small amount of movement can cause severe damage to structures and utilities.

- *Submarine landslides* – These landslides are apt to go unnoticed unless they trigger noticeable water waves or damage submarine utilities.

The Northern Cascade foothills are susceptible to landslides in bedrock. The foothills are subject to moist Pacific storms; the shape and contour of the foothills enhance the amount and intensity of precipitation.

- *Debris Flows* – The combination of thin, permeable soils on a relatively smooth and impermeable substrate, a steep slope, and intense precipitation are conducive to debris flows. These slides commonly enter flood-swollen streams, becoming more mobile than that of an isolated bluff avalanche and traveling miles from their point of origin.

- *Bedrock landslides* – Most landslides in bedrock are in folded and faulted sandstone that ring much of the northern lowland. Nearly all are ancient events probably triggered by removal of support by melting snow or erosion. In general, most are now stable.

<u>Southwest Washington</u>

The primary characteristics of this landslide province are the lack of glaciation and only localized exposure to glacial melt waters. In places, surfaces in this province have been exposed to weathering processes for millions of years. Much of the province has deeply dissected terrain, with gentle slopes uncommon.

- *Earth flow or Slump/earth flow*– This is the dominant form of landslide in the province. Both ancient and active earth flows are common, not only in the high and steep terrain, but also in the low, rolling hills of the Chehalis-Centralia area. Stream erosion along the toes of the flow usually causes reactivation of these landslides. Excavations, such as those for freeway construction, may also reactivate dormant earth flows or start new ones.

- *Debris flows* – These types of landslides are locally a problem in the western Cascades and Olympic mountains; they tend to occur where the rocks are strong and relatively un-weathered. These rocks tend to have steep slopes and smooth surfaces overlain by thin soils. Intense rainstorms, or rain on the wet snow in the mountains trigger these landslides.

<u>Cascade Range</u>

This landslide province has a number of different landslide types because of its glacial history and climate. There are three subprovinces in the Cascades – north of

Snoqualmie Pass, south of the pass, and the stratovolcanoes, which have distinct slope stability characteristics.

The valley walls of the Cascades north of Snoqualmie Pass have areas of small rock falls, but have relatively few landslides otherwise.

South of Snoqualmie Pass, most peaks are lower and made up of predominantly volcanic rock; earth flows and block slides in bedrock are the most common types of landslides. Large landslides in bedrock occur in the Columbia River gorge area of the southern Cascades; more than 50 square miles of landslides are in the gorge, but less than 10 percent of the area is active.

The state's five stratovolcanoes – Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens and Mount Adams – have layered rock lying parallel to the slopes. Deposits are prone to failure, with rock on upper slopes weakened by hydrothermal action. Small rock falls and rock avalanches are common localized hazards on the slopes of the volcanoes; earthquakes have triggered large rock avalanches.

<u>Okanogan Highlands</u>

This landslide province extends from the slopes of the North Cascades in the west to the Selkirk Mountains in the northeast corner of the state. The primary slope stability problem in this province is in the sediments within and along the boundary of the highlands. Thick sections of sediments along the valleys of the Columbia, Spokane, and Sanpoil Rivers are the result of repeated damming of the Columbia River by lobes of the continental ice sheet and repeated catastrophic floods from breached ice dams.

The occurrence of new landslides and the reactivation of old landslides increased dramatically with the filling of reservoirs behind the Grand Coulee and Chief Joseph dams. Drawdowns for flood control and power generation also trigger new landslides and/or reactivate and extend old ones. Some of the landslide complexes extend for thousands of feet along the lakeshores, have head scarps in terraces 300 feet or more above reservoir level and extend well below its surface. With landslide activity common along hundreds of miles of shoreline, one hazard in such a setting is water waves generated by fast-moving landslide masses.

<u>Columbia Basin</u>

This landslide province has extensive layers of sediments between, intermingling with, and overlaying basalt flows; sediments generally are thicker in the western part of the province.

Landslides in this province include slope failures in bedrock and landslides in overlying sediments. Bedrock slope failures are most common in the form of very large ancient slumps or slumps/earth flows; a final triggering mechanism appears to be over-steepening or removal of toe support by streams or glacial floods. Sediments contemporary with or overlying Columbia River basalt make up a major part of the large landslide complexes in the province. Major landslide problems were encountered within these sediments during the relocation of transportation routes required by the filling of the reservoir behind the John Day dam.

Irrigation in the Columbia Basin compounds the province's landslide problems. For example, irrigation near Pasco has increased drainage and landslide problems ten-fold since 1957. New landslides and reactivation of ancient landslide complexes occurred in the bluffs along the Columbia River upstream of Richland.

<u>Olympic Mountains</u>

Underlain by sedimentary and volcanic rocks, the Olympic Mountains have both slope stability conditions and a variety of landslide types that occur throughout the state.

Some lower valleys without glaciers have thick sections of weathered soil and bedrock comparable to those in the Southwest Washington landslide province. In such areas, earth flows are extensive. Adjacent valleys with glaciers have soils comparable in age, texture, physical properties and behavior to the sediments in the Puget Lowland.

Recently glaciated valleys that penetrate core rocks have landslide problems similar to those in the North Cascades. Slopes in sediments undercut by wave action along the Strait of Juan de Fuca experience extensive slumps and earth flows or block slides similar to failures in the southern Cascades.

Significant Historic Landslides[5, 6, 7, 8, 9, 10, 11, 12, 13, 14]

1550 – 1700 (est.) – The Bonneville Landslide in the Columbia River Gorge 30 miles east of Vancouver created a temporary dam in the river. The landslide from Table Mountain shoved the river a mile off course and created a lake that may have stretched east for 100 miles. It is the youngest and largest of four landslides that make up the 14-square mile Cascade Landslide Complex north of the Columbia River near Cascade Locks and Stevenson. Explorers Lewis and Clark documented the landslide and its effects in 1803.

Early 1800s – Historical accounts among the Snohomish people describe a large landslide at Camano Head that sent a tsunami south toward Hat Island. According to tribal accounts, the landslide sounded like thunder, buried a small village and created a large volume of dust. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake. Camano Head is at the south end of Camano Island in Puget Sound.

1872 – A landslide, triggered by a 6.8 (est.) magnitude earthquake, reportedly blocked the flow of the Columbia River north of Wenatchee for several days (although some scientists dispute this).

1890s – A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The wave killed one person. This poorly documented event occurred in the 1890s.

1891 – Two large earthquake shocks and submarine landslides on November 29 caused water in Lake Washington and Puget Sound to surge onto beaches two feet above the high water mark, rocking vessels that had just pulled away from wharves.

1894 – A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. These events carried away a railroad track and roadway, resulting in two deaths.

1944 to 1953 – Massive landslides generated a number of inland tsunamis in Lake Roosevelt in Eastern Washington:

- *April 8, 1944* - A four to five million cubic yard landslide from Reed Terrace generated a 30-foot wave, 5,000 feet away on the opposite shore of the lake about 98 miles above Grand Coulee Dam.

- *July 27, 1949* - A two to three million cubic yard landslide near the mouth of Hawk Creek created a 65-foot wave that crossed the lake about 35 miles above Grand Coulee Dam; people 20 miles away observed the wave.

- *February 23, 1951* – A 100,000 to 200,000 cubic yard landslide just north of Kettle Falls created a wave that picked up logs at the Harter Lumber Company Mill and flung them through the mill 10 feet above lake level.

- *April 10 – 13, 1952* – A 15 million cubic yard landslide three miles below the Kettle Falls Bridge created a 65-foot wave that struck the opposite shore of the lake. People observed some waves six miles up the lake.

- *October 13, 1952* – A landslide 98 miles upstream of Grand Coulee Dam created a wave that broke tugboats and barges loose from their moorings at the Lafferty Transportation Company six miles away. It also swept logs and other debris over a large area above lake level.

- *February 1953* – A series of landslides about 100 miles upstream from Grand Coulee Dam generated a number of waves that crossed the lake and hit the opposite shore 16 feet above lake level. On average, observed waves crossed the 5,000-foot wide lake in about 90 seconds.

- *April – August 1953* – Landslides originating in Reed Terrace caused waves in the lake at least 11 different times. The largest wave to hit the opposite shore was 65 feet high and observed six miles away. Velocity of one of the series of waves was about 45 miles per hour.

1949 – A landslide three days after the April 16 magnitude 7.1 earthquake generated a tsunami in the Narrows of Puget Sound near Tacoma. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave away and slid into Puget Sound. The slide narrowly missed a row of waterfront homes, but the tsunami damaged them.

1965 – Ground shaking produced by the April 29 Seattle-Tacoma earthquake generated 21 landslides within about 60 miles of the epicenter. Among landslides reported include the following:

- Slumping along a steep slope adjacent to 36th Avenue SW near Admiral Way in West Seattle, and a landslide that uncovered an underground stream that overflowed a creek and broke a water main at Carkeek Park in South Seattle.

- Landslides on Lake Holm Road east of Auburn.

- Part of Crescent Lake Road near Gig Harbor sinking and being covered by water.

- Cracking of canyon walls of the Nisqually River gorge and landslides into the river and onto roads near LaGrande.

- Landslides on both Jones Road and Devils Elbow Road near Maple Valley.

- A large landslide on the southwest slope of Mount Si near North Bend.

- Landslides that heavily damaged Deschutes Parkway around Capitol Lake in Olympia and broke a sewer line and railroad tracks near Tumwater.

- A landslide undermined a road, and a portion of beach heaved at Suquamish.

1980 – A 5.1 magnitude earthquake near Mount St. Helens on May 18 triggered the largest landslide – an estimated 3.7 billion cubic yards, or 0.67 cubic miles – in recorded history. The earthquake dislodged the summit and bulging north face of the volcano, depressurizing the volcano's magma system, triggering powerful explosions and a massive eruption.

1999 – Landslides affected homes and private and county roads at Carlyon Beach/Hunter Point, Sunrise Beach, and Sunset Beach in Thurston County. Forty-four homes were declared unsafe for human inhabitance. At Sunrise Beach, Thurston County government and property owners were successful with engineering and construction efforts to stop the slide; property owners paid for these actions. Landslides continue at Carlyon Beach.

Recent Disasters with Landslides

February 1996 – Storms and Landslides[15, 16]

Stafford Act disaster assistance provided – $113 million. Small Business Administration disaster loans approved - $61.2 million.

The National Weather Service, Seattle Forecast Office considers this storm one of the top 10 weather events in Washington during the 20th Century.

Near-record snowfall in January followed by warm, heavy rain, mild temperatures and snowmelt in February caused flooding, mudflows and landslides throughout the state. The storm caused three deaths, and 10 people were injured. Landslides damaged or destroyed nearly 8,000 homes, and closed traffic along major highways for several days. Damage from all causes throughout the Pacific Northwest was at least $800 million.

The landslide that created the most significant impact blocked Interstate 5 and the state's main north-south railroad tracks three miles north of Woodland, Cowlitz County. The initial slide on February 8 blocked northbound lanes of I-5; a second, larger slide covered all lanes of the freeway as well as the railroad tracks to the west. It took crews until February 19 to fully reopen the interstate.

The highest concentration of landslides occurred at the northwest edge of the Blue Mountains near Walla Walla. The main areas affected were the Mill Creek, Blue Creek, Touchet, Tucannon, and Walla Walla drainages. Debris flows were most numerous on open, grassy hillsides. In the Mill Creek area, debris flows destroyed seven vehicles and five homes. Similar occurrences of flooding and landslides took place in 1931 and 1964.

Seattle recorded more than 40 landslides during the winter, about two-thirds related to this storm. Most involved failure from steep coastal cliffs. Landslides damaged or threatened homes on Perkins Lane, Brygger Drive, Laurelcrest Drive, and California Way. Elsewhere in King County, a landslide blocked State Route 410 east of Enumclaw.

In Pierce County, landslides destroyed two homes and damaged another along with utility lines at Salmon Beach, Tacoma. A landslide hit two homes and covered a portion of Marine View Drive, and closed southbound lanes of Schuster Parkway. North of Gig Harbor, two debris flows destroyed one house and damaged three others. A landslide pushed two locomotives and two rail cars into Puget Sound, resulting in a 3,000-gallon fuel spill. Numerous debris flows damaged State Route 165 and undermined a bridge abutment at the Carbon River near Carbonado.

In Thurston County, numerous landslides in the Olympia area severed two sewer lines resulting in a 6 million gallon sewage discharge into Capitol Lake. Numerous debris flows occurred on the bluffs below the Capitol Campus that covered railroad tracks and an adjacent road, and just missed a steam plant that produced heat for the campus.

Lewis County had the largest landslide, with an estimated 1.5 million cubic yards of debris; it destroyed a house five miles east of Glenoma. Landslides blocked State Route 504 in two places by landslides in Kid Valley, and a landslide closed State Route 7 near Mineral Lake for two days.

In Clark County, numerous landslides blocked rail lines near Vancouver Lake, and a train was buried by debris. In Hazel Dell, a house was broken in two by a debris flow. Landslides closed or partially covered State Route 14 in 15 different areas for 80 miles between Washougal and Wishram. Just south of Woodland, a landslide predating the February 1996 storm but accelerated by it covered the Northwest Pacific Highway.

In Skamania County near Stevenson, a large reactivated landslide complex removed three homes from their foundations, and a debris flow covered State Route 141 near White Salmon.

Other landslide damage included:

- Numerous debris flows and landslides that damaged local and county roads and closed State Route 4 west of Skamokawa, Wahkiakum County.

- Numerous debris flows partially covered State Route 503 Lewis River Road.

December 1996 – January 1997 Holiday Storms and Landslides[17, 18, 19]

Federal Disaster #1159. Stafford Act disaster assistance provided – $83 million. Small Business Administration loans approved – $31.7 million.

Snowmelt and rainfall in late December 1996 and January 1997 triggered hundreds of landslides and debris flows in the steep bluffs and ravines that border Puget Sound, Lake Washington, and the larger river valleys between late December 1996 and mid March 1997. Landslides caused the deaths of at least four people, millions of dollars of damage to public and private property, lost revenues, traffic diversions, and other losses.

December precipitation was 191 percent of normal. More than 130 landslides occurred between Seattle and Everett, primarily along shorelines. Although shallow slides and debris flows were the most common slope failures, many deep-seated slides also occurred. Many bluffs and steep hillsides were sites of recurring failures.

Most landslides that resulted from these storms occurred mainly in and north of Seattle – along the bluffs of Puget Sound, Lake Washington, Lake Union, Portage Bay, West Seattle, Magnolia Bluff, and along the I-5 corridor. Many smaller landslides were scattered west and south of Seattle in Kitsap and Pierce counties.

A landslide on January 15 derailed five cars of a freight train on the shore of Puget Sound midway between Seattle and Everett. Freight traffic was running again although at reduced speed by January 24, while Amtrak was not able to use the track for several weeks while safety issues were resolved.

A debris flow slide on January 19 killed a family of four at Rolling Bay Walk on Bainbridge Island. A number of debris flows from the storms were visible along the undeveloped bluff not far from the house; more debris flows occurred at Rolling Bay Walk on March 18 and 19, damaging two homes and pushing a third onto the beach.

About 20 to 30 landslides occurred in Pierce County, including along Schuster Parkway, Salmon Beach, and the Narrows. One landslide cut phone service to homes on Salmon Beach.

Saturation of soils in Whatcom and Clark Counties caused landslides that resulted in the rupture of two interstate natural gas lines, causing explosions; no injuries reported. Residents near the line in Whatcom County evacuated until it was shut down. In Clark County, the incident resulted in a fire that caused significant damage to a nearby commercial structure under construction.

October 1998 – Aldercrest Landslide Disaster[20, 21]

Federal Disaster #1255. Stafford Act disaster assistance provided – $12.1 million. Small Business Administration disaster loans approved - $38.7 million.

The Aldercrest Landslide Disaster is the second-worst landslide disaster in United States history. Of the 137 homes in the east Kelso, Cowlitz County, neighborhood, the landslide destroyed or badly damaged 126 homes; a demolition contractor eventually removed the damaged structures.

This ancient landslide began moving in March 1998 after soils were saturated by three straight years of above average rainfall.

Eleven homeowners remained on a bluff above the slide; geologists say their houses eventually will succumb to the slide.

Nisqually Earthquake – February 28, 2001[22]

Federal Disaster #1361. Stafford Act disaster assistance provided to date – est. $155.9 million. Small Business Administration disaster loans approved - $84.3 million. Federal Highway Administration emergency relief provided to date - $93.8 million.

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. It produced a number of significant, but widely scattered landslides that caused damage resulting in direct monetary losses of $34.3 million; indirect costs such as loss of productivity, revenues and tax receipts, reduced real estate values, injuries, and environmental impacts are not included.

Among the significant landslides caused by the Nisqually earthquake are the following:

Salmon Beach, Tacoma – A 1,300 cubic yard landslide demolished two homes at the base of the bluff. The landslide damaged sewer, water and electrical lines. A much larger slide – estimated at 13,000 to 26,000 cubic yards – moved at the top of the bluff threatening another eight homes. This waterfront community on the Tacoma Narrows also experienced landslide damage during the 1949 earthquake. Estimated damage caused by the smaller landslide is $1.5 million.

Cedar River, Renton – Two landslides occurred along the banks of the Cedar River. One, estimated at 50,000 cubic yards, demolished 200 yards of a flood control facility and blocked the river until a ditch was dug through the debris. A second carried 10,000 cubic yards of material into a house, breaking it in two and filling half the structure with debris. The landslide narrowly missed burying the home's occupant. Estimated damage caused by these slides is $1.7 million.

Capitol Lake/Deschutes Parkway, Olympia – The parkway experienced significant damage from lateral spreading, liquefaction and ground failure during the earthquake, as well as from a landslide six weeks later. Several lateral spread landslides occurred around the margins of Capitol Lake; they damaged water and sewer lines as well as Marathon Park. Estimated damage caused by these landslides is $22.2 million.

Maplewild Avenue, Burien – Five homes perched along a steep slope sustained structural damage when underlying fill formed a landslide. One house was demolished and two others badly damaged. The street also was damaged between 29th Place SW and 33rd Avenue SW. Estimated damage caused by the landslide is $7.6 million.

Tolmie State Park, near Olympia – Lateral spreading damaged sewer and water lines, bridges, trails and a kitchen shelter, resulting in temporary closure of the day-use marine park. Estimated damage caused by the landslides is $348,000.

Sunset Lake-Trosper Memorial Trailer Park, near Tumwater – A lateral spread and other failures damaged the perimeter road, a two-inch natural gas line serving the trailer park and a number of mobile homes; damage estimates not available.

U.S. Highway 101, Thurston County – The northbound lanes of the highway near its junction with State Route 8 west of Olympia slid away during the earthquake. A slump/debris flow of about 20,000 cubic yards removed one lane of the highway and flowed down a slope between two homes before ending up on a surface street below. Estimate damage caused by the slide $919,570.

Other areas where landslide caused damage includes King County International Airport/Boeing Field, Harbor Island in Seattle, Chambers Creek near Steilacoom, State Route 302 near Allyn, State Route 202 near Snoqualmie, Victor Fill near Port Orchard, and Interstate 405 at 44th Street in Renton.

October 2003 – Floods and Storms

Federal Disaster #1499. Stafford Act disaster assistance provided to date – $ ________ million. Small Business Administration disaster loans approved – $____ million. *(Information to come)*

Heavy rainfall caused flooding severe flooding and landslides in 15 counties. Landslides or ground failures caused temporary closures on nine state highways. Among the most significant events were a series of mud and rockslides that closed State Route 20 between Skagit and Okanogan Counties, and a sinkhole on State Route 112 in Clallam County that cutoff the Makah Indian Reservation. Other landslides transportation problems included debris over the roadway or lodged beneath bridges on U.S. Highway 101 in Jefferson and Mason Counties, U.S. Highway 2 in Snohomish County, and State Route 410 in Pierce County.

The most significant was a series of rockslides that closed State Route 20, the North Cascades Highway. The largest, estimated at two to three million cubic yards, demolished the highway and cutoff the town of Diablo. People and supplies were shuttled in and out of the town via helicopter for a month during the winter. The highway reopened April 8, 2004 for the season (the highway closes during the winter due to the threat of snow avalanche). Electronic monitoring devices connected to warning signs installed to listen for rock movement and to warn drivers if a further rock fall occurs.

Jurisdictions Vulnerable to Landslides

The following jurisdictions have the greatest vulnerability to landslides, based on descriptions of events and damages described above, as well as information from landslide experts from the Washington Department of Natural Resources and the U.S. Geologic Survey consulted for this profile.

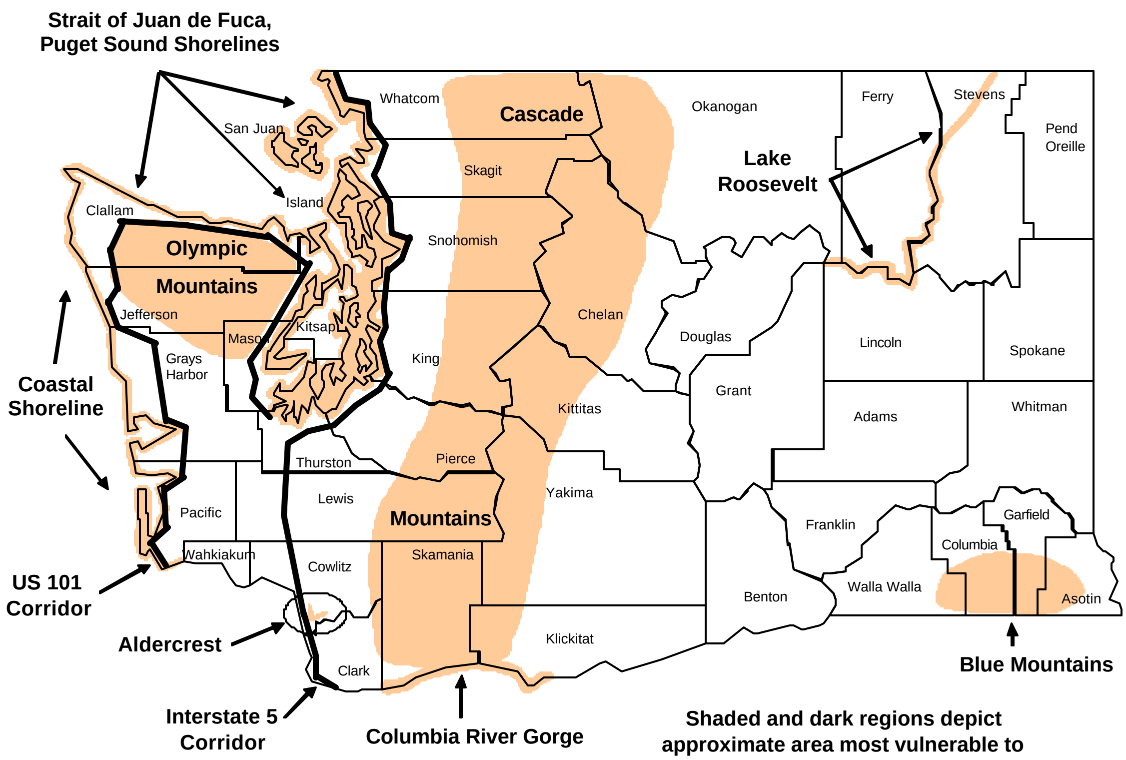
Asotin	Chelan	Clallam	Clark	Columbia
Cowlitz	Ferry	Garfield	Grays Harbor	Island
Jefferson	King	Kitsap	Kittitas	Klickitat
Lewis	Lincoln	Mason	Okanogan	Pacific
Pierce	San Juan	Skagit	Skamania	Snohomish
Stevens	Thurston	Walla Walla	Whatcom	Yakima

Parts of these jurisdictions have one or more of the following areas that are prone to landslides:

- Shorelines of Pacific Coast, Puget Sound and Hood Canal.
- Shoreline of Lake Roosevelt and the Columbia River Gorge.
- Slopes of the Blue, Cascade, and Olympic mountain ranges.

- Corridors of Interstate 5 and U.S. Highway 101.

Areas Most Vulnerable to Landslide



Shaded and dark regions depict approximate area most vulnerable to landslide.

State Agency Structures At Risk			**PRELIMINARY ASSESSMENT**
Number and Function of Buildings	**No. of Affected Staff / Visitors / Residents**	**Approx. Value of Owned Structures**	**Approx. Value of Contents All Structures**
Total at-risk buildings: State agencies participating in this plan identified 485 facilities as being potentially at-risk to direct damage or to the indirect impacts of landslides or ground failures.	33,672	$917,643,507	$644,497,961

Function of at-risk buildings: Included in the state facilities potentially at-risk to landslide and ground failure are the following:

- Eight buildings and the lifeline infrastructure on the main campus of Western Washington University.
- A half-dozen buildings of the State Capitol Campus including the Legislative Building, Governor's Mansion, Temple of Justice, General Administration Building, and the campus powerhouse.
- Campus of the Naselle Youth Camp for juvenile offenders.
- Campuses of the Rainier School, Western State Hospital, and Lakeland School for individuals with mental and physical disabilities.
- About 240 general office and client service offices that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

More detailed narratives on at-risk facilities can be found in the Region profiles, Tab 7.2.1 – Tab 7.2.9.

Eight state highways considered emphasis corridors because of their importance to movement of people and freight are potentially at risk to landslide and ground failure:

1. Interstate 5
2. Interstate 90
3. U.S. Highway 2
4. U.S. Highway 12
5. U.S. Highway 97
6. U.S. Highway 101
7. U.S. Highway 395
8. State Route 20

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their construction on poor soils in shoreline areas.

Total at-risk critical facilities: State agencies participating in this plan identified 216 facilities as being potentially at-risk to direct damage or to the indirect impacts of landslides or ground failures.	23,112	$682,408,680	$493,393,487

Function of at-risk critical facilities: Included in the state facilities potentially at-risk to landslide and ground failure are the following:

- Eight buildings and the lifeline infrastructure on the main campus of Western Washington University.
- A half-dozen buildings of the State Capitol Campus including the Legislative Building, Governor's Mansion, Temple of Justice, General Administration Building, and the campus powerhouse.
- Buildings on the campus of the Naselle Youth Camp for juvenile offenders.
- Buildings on the campuses of the Rainier School, Western State Hospital, and Lakeland School for individuals with mental and physical disabilities.
- About 70 general office and client service offices that include those serving individuals and families on public assistance, providing employment and training services, driver licensing, and liquor sales.

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[1] *Washington State 2001 Hazard Identification and Vulnerability Assessment*, Washington State Military Department, Emergency Management Division, April 2001.

[2] *Hazard Fact Sheet*, U.S. Geological Survey, Landslide Information Center, March 2002, <http://landslides.usgs.gov/html_files/nlic/page5.html>, (August 12, 2003).

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